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               SPECTROSCOPIC OBSERVATION OF FAST IONS FROM LASER-PRODUCED PLAS--ETC(U)
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Spectroscopic Observation of Fast Ions from Laser-Produced Plasmas
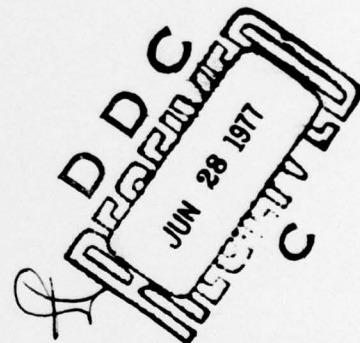
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Using a time-of-flight spectroscopic technique, measurements were made of the ion energy distributions of very fast ions and thermal ions produced when a 7-15 J, 100 psec Nd:glass laser pulse (1.06 μm) strikes a $(CH_2)_n$ slab target. Ion energies greater than 0.5 MeV have been observed for the first time with this technique of measurement. A simultaneous comparison is made between the signal of an ion charge collector placed 30 cm from the target and the intensity of the C VI 3434 Å ion line at 1 cm from the target.
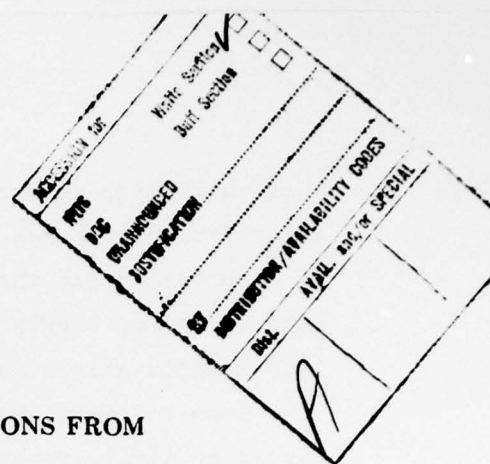
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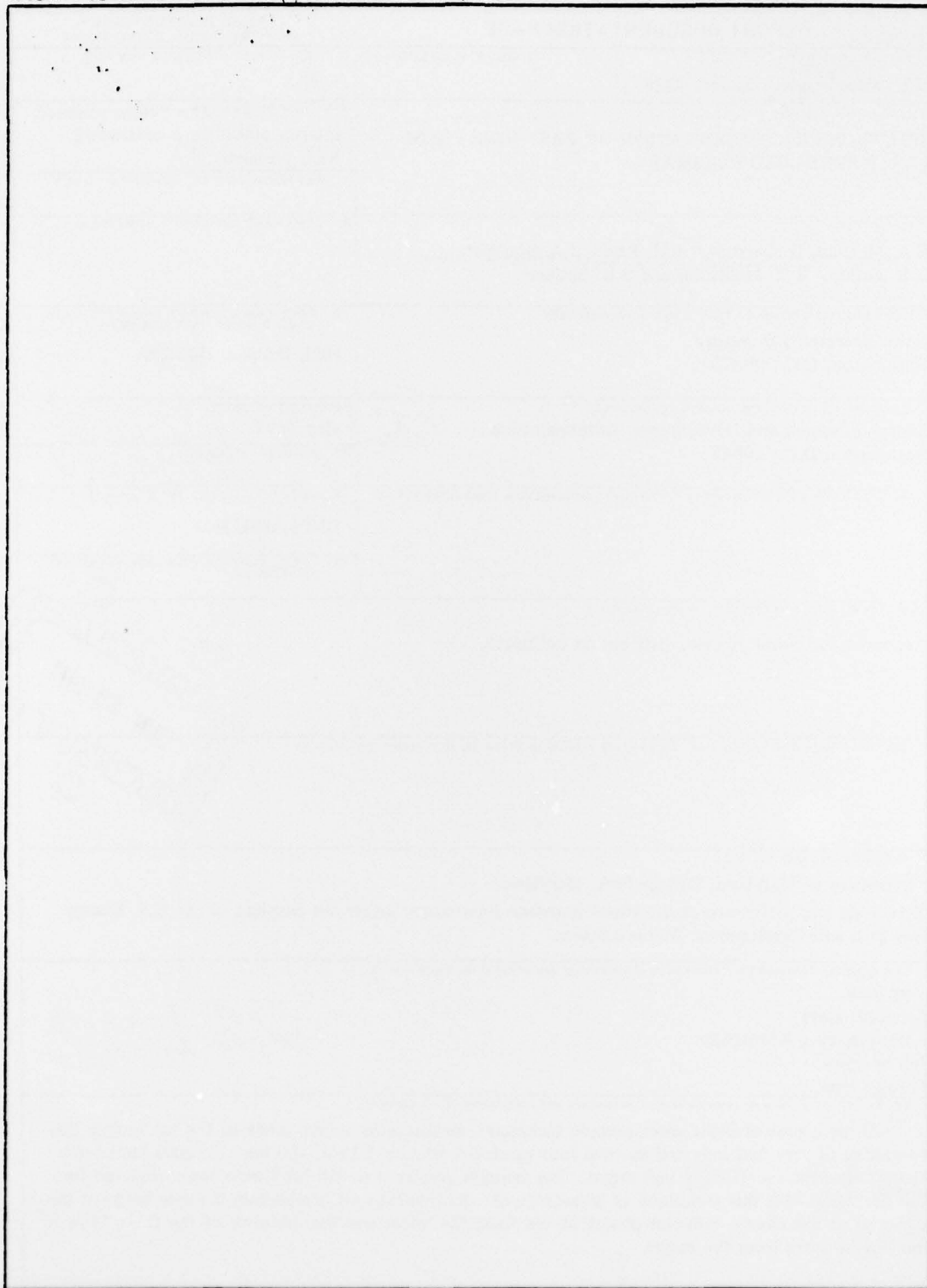
SPECTROSCOPIC OBSERVATION OF FAST IONS FROM
LASER-PRODUCED PLASMAS

Exceedingly energetic ions ($v > 10^8$ cm sec^{-1}) are observed when high irradiance laser beams strike solid targets.[1] It has been established in these experiments that a large fraction of the absorbed laser energy is emitted in the form of kinetic energy of ions.[2,3] The usual technique to measure the ion energy distribution is to use ion charge collectors, or an electrostatic or magnetic ion analyzer. In this paper a spectroscopic technique[4-7] is described that allows measurements of the velocity distribution of the ions of a particular species of ionization. Further advantages of the technique are that simultaneous measurements can be made of both the high energy ions as well as the thermal ions and that measurements can be made close to the target (1-20 mm) and within the lens cone, without interfering with the incident laser beam. Typically, the spectral line intensities can be observed out to several centimeters from the target surface. Here we report the first observations of fast ions with energies beyond ~ 0.5 MeV using this optical technique. Previous studies[4] using this technique, mostly at much lower incident laser power densities, did not show any ions with energies > 7 keV.

The excited ions are produced when a Nd:glass laser pulse (7-15 J, 100 psec) is focused with an f/1.9 aspheric lens onto a polyethylene $(CH_2)_n$ slab target in an evacuated ($\sim 3 \times 10^{-4}$ Torr) chamber, as shown in Fig. 1. The half-energy focal spot diameter was 45 um, yielding an average focal irradiance of 10^{15}-10^{16} W/cm^2. The plasma that is created is observed perpendicular to the laser axis by a 3/4-m monochromator and a fast photomultiplier (RCA-1P28). The

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photomultiplier temporally resolves 5.5 Å of the central intensity of a particular spectral line. The distance from the target to the point of observation and the time-of-flight of an ion bunch determines the mean velocity. Reflective optics were used to achieve an achromatic system which allows the optics to be aligned in the visible and then used down to about 2000 Å. The position of observation could be varied by simply rotating the concave mirror with a spatial resolution of ~ 0.1 mm. The photomultiplier was proved to be linear in the operating range, and the rise-time of the photomultiplier and recording electronics is better than 3 nsec. The time marker t = 0 was determined by observing, through the same optical system the initial rise of the $2\omega_o$ (5320 Å) light generated at the <u>target surface</u>.

A time-integrated photographic spectrum (2000 Å - 5000 Å) showed many spectral lines of the carbon ions, C I - C VI. The continuum radiation was intense only within a few millimeters from the target surface and was below the noise level beyond 1 cm from the surface.

A typical oscillogram of the C VI 3434 Å (n = 6-7) line is shown in Fig. 2. Here, the spectrograph was aligned to view the plasma 1 cm from the target. This trace shows low-intensity, but distinguishable, fast ion signals (< 10 nsec) followed by the larger, more slowly rising peak due to the bulk plasma expansion (thermal ions). The first peak of the trace corresponds to an ion energy ~ 560 keV, the second peak to an energy of ≈ 100 keV, and the last peak, or thermal peak, corresponds to an energy of ~ 14 keV. The accuracy of the energy measurements of the fastest ions is about $\pm 50\%$ due to the comparable electronic and signal rise-times and the short time-of-flight. However, the accuracy of the thermal peak energy should be about $\pm 5\%$ since it occurs at a later time. The temporal accuracy of the fast ion measurement could be improved by making the measurement at 2 cm from the target surface, although the signal amplitude would decrease.

In Fig. 3 a comparison is made between the signal of an ion charge collector placed 30 cm from the target and 27° from the laser beam,

and the spectral intensity of the C VI 3434 Å ion line at 1 cm from
the target on the same shot. The target normal was rotated 10° with
respect to the laser axis, and the laser beam was vertically polarized
(s-polarization). The C VI curve has been normalized to the same
velocity scale as the ion charge collector. Other than the initial
spikes in the ion charge collector curve, the two curves are quite
similar. For example, there are peaks on both curves corresponding
to energies of ~ 560 keV, ~ 100 keV, and ~ 15 keV. Other than minor
differences in the energy at which the peaks occur, the largest
difference between the two signals are in details in the structure of
the ion charge collector signal. Other measurements using an electro-
static ion analyzer show that these narrow early peaks in the ion
charge collector signal are mainly due to hydrogen ions.[8] Also, we
would not expect the amplitude of the two signals to track precisely
since the secondary electron emission in the charge collector is
dependent on the particle energy, and the line intensity is not simply
related to the total number of ions. Although there are shot-to-shot
variations in the fast ion traces, the general agreement between the
ion charge collector and the C VI signals persisted for the shots taken
under these conditions. Fast ion peaks were not seen in the
oscillograms for carbon ions lower than C VI. This result is not
fully understood at this time, but it may be that the fastest ions come
from a very high temperature region where the ions are completely
stripped and have just begun to pick up electrons on the way out.
Recombination is evidently not fast enough to produce a significant
population of lower charged states. Also, there is the possibility
that we do not see fast ions in some of the lower stages of ionization
because of differences in the radiative lifetimes of the transitions
involved.[9]

In conclusion, this optical technique allows independent
determinations of ion energies in laser-produced plasmas and
unambiguously separates the various species of ionization. Some
uncertainties encountered using the more common ion detectors are,

therefore, avoided. Measurements can be made less than 1 cm from the target surface and within the lens cone, where other ion detectors cannot easily be used. As has been pointed out by Boland, Irons, and McWhirter,[4] it is possible using this technique and a separate measurement of the electron density and temperature to get absolute number densities of the various species of ions, and thus to determine the amount of energy in each type of ion and also the energy in the fast and thermal ions.

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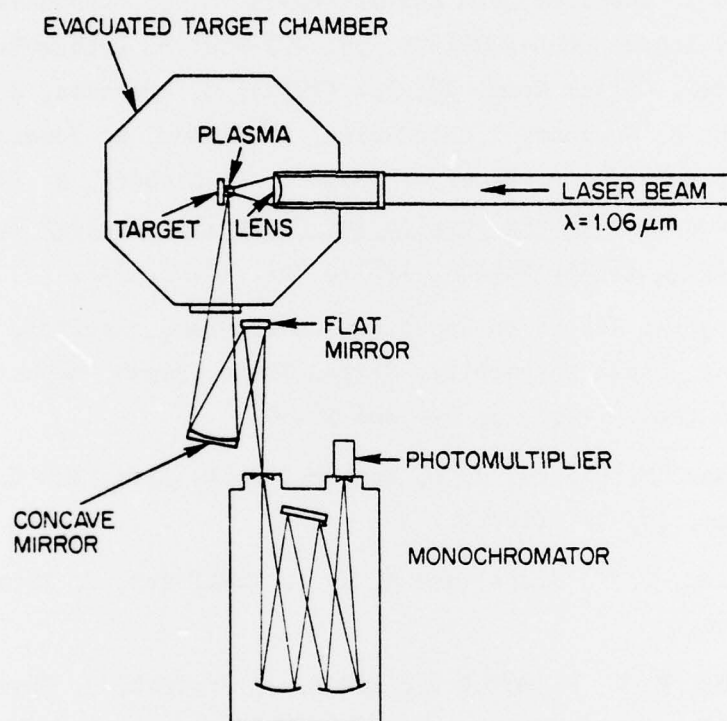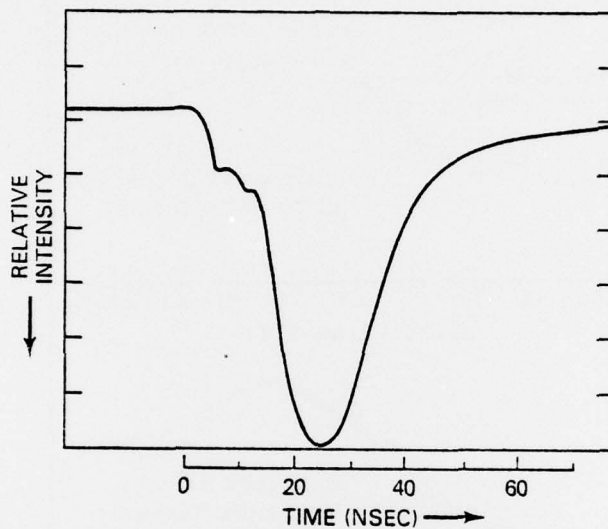
Fig. 1 — Experimental arrangement

Fig. 2 — Oscillogram of the C VI 3434 Å ion line intensity observed 1 cm from the target surface. The time t = 0 is the time the laser pulse (7 J, 100 psec) initially strikes the target.
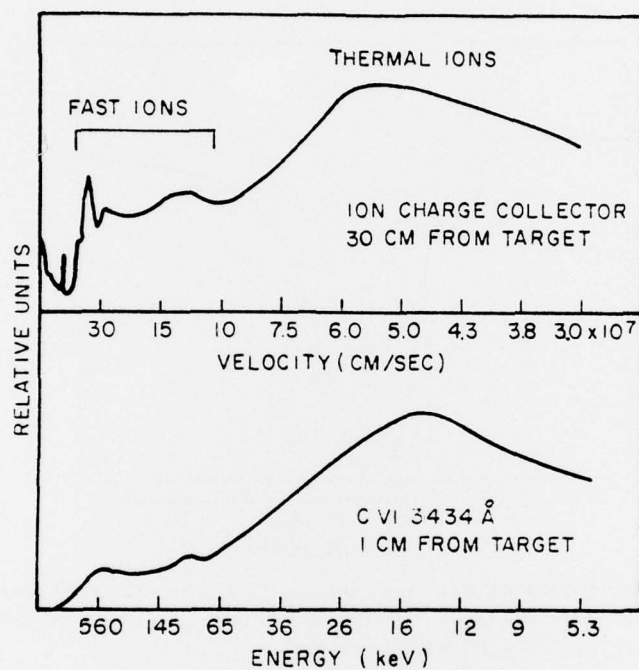
Fig. 3 — A comparison of the time trace of an ion charge collector and the intensity of the C VI 3434 Å ion line for the same laser shot. Both curves are normalized to the same energy and velocity scales. On the ion charge collector curve the spike adjacent to the left ordinate is due to x-ray flash and the next very sharp spike may be due to a spurious electromagnetic noise signal.